Towards Control of *Real* Thermal Systems

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"Most PowerPoint users are drawn to it because they are stupid."

-Edward Tufte
(Yale professor emeritus of political science, computer science, and statistics and author of *The Visual Display of Quantitative Information*)

"Many a small thing has been made large by the right kind of advertising."

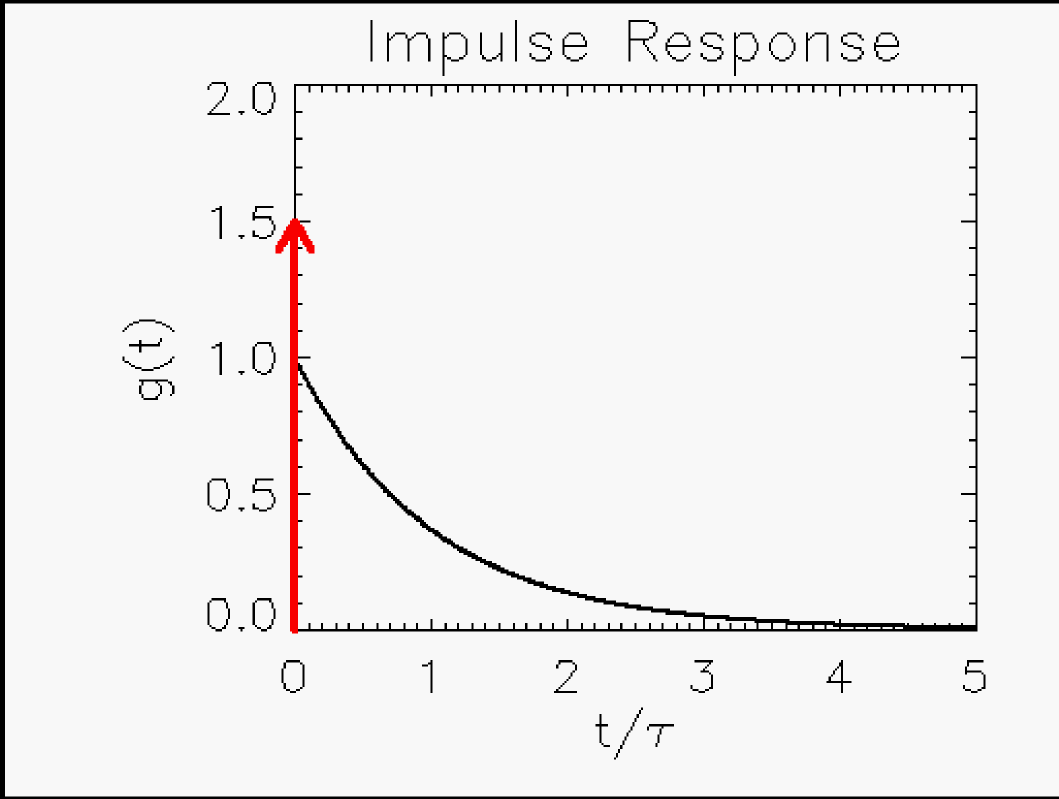
-Mark Twain (from *A Connecticut Yankee in King Arthur's Court*)

Complexity of Thermal Systems

- Infinite dimensional: continuous system is governed by system of PDEs
- Sensor and heater not likely to be co-located (often impossible) resulting in a stimulus-response lag
- System response can be non-linear
- Nevertheless a first-order linear model can be used to design a temperature control system

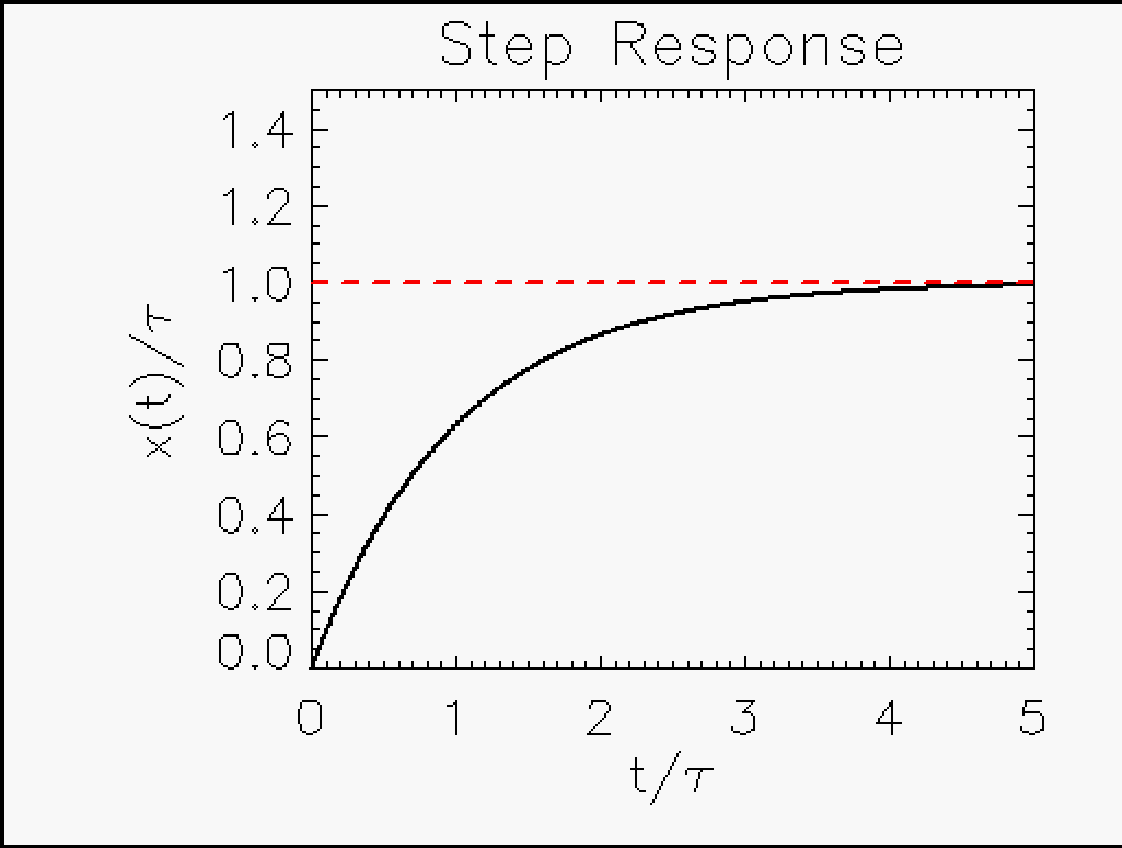
First-Order System Response

- Thermal systems can be roughly modeled as 1st order linear systems
- 1st order linear systems have a time constant, displaying an exponential impulse response



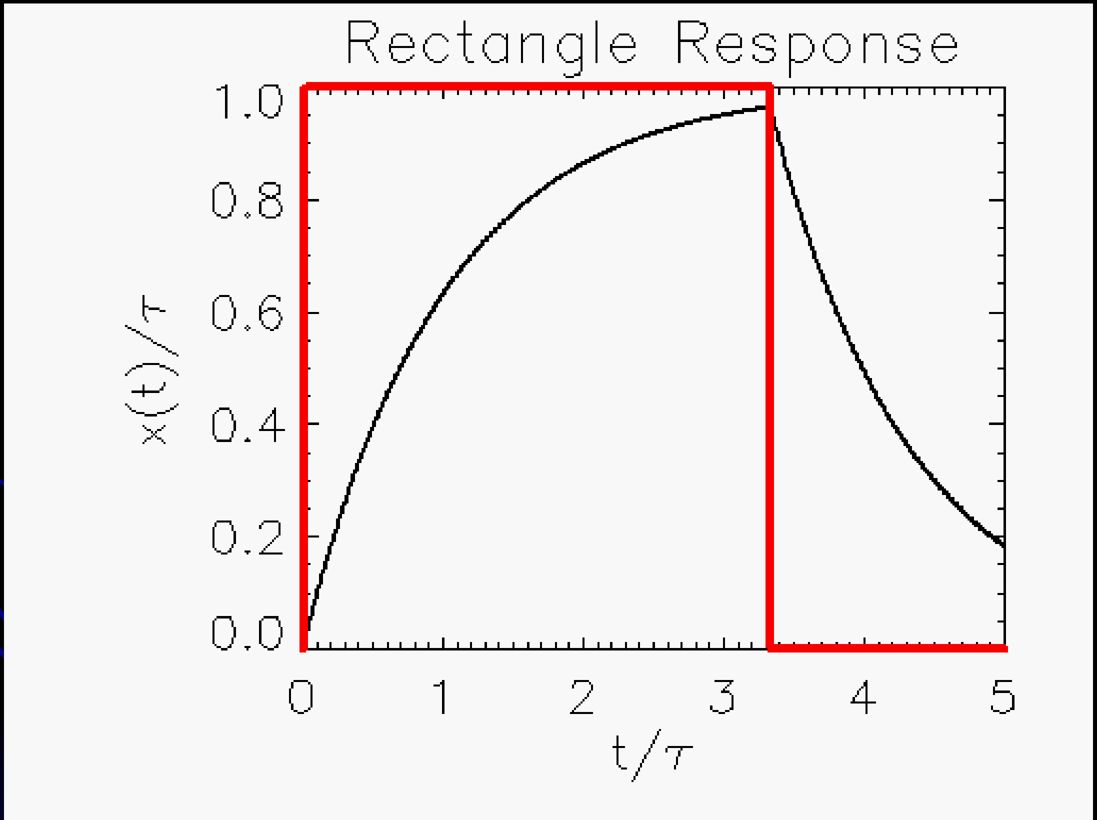
First-Order System Response

- Step increase displays an exponential approach to a constant value



First-Order System Response

- Rectangle response has rising exponential + decaying exponential



Tuning PID Control Parameters Requires Knowledge of System Time Constants

<u>Problem:</u>

How can we determine the time constant(s) for the NIST CCRs?

<u>Theoretical Answer:</u>

Measure the response to step changes over a broad range of temperatures and automatically fit to the appropriate simplified theoretical response function.

Problem with the First-Order Model

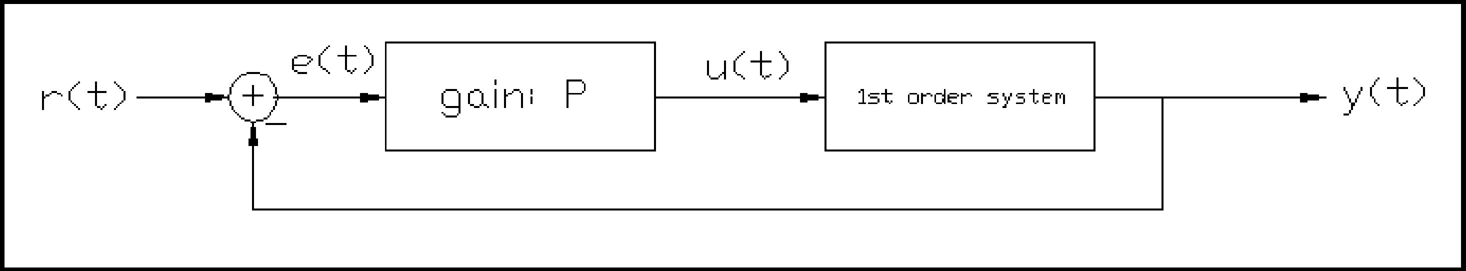
- Time "constant" is <u>not</u> constant but depends on the temperature

- To first order the time constant is proportional to the heat capacity: $\tau = RC$ where R is the thermal resistance and C is the heat capacity.

- Must measure the time constant over a broad range of temperatures to get the temperature dependence of $\tau(T)$.

Aside

- If real thermal systems were truly first-order then you would be able to control them very well by simply cranking up the gain!



$y' + (1/\tau)y = u$; $u = Pe$; $e = r - y$

$y' = -(P + 1/\tau)y + Pr$

$y(t \to \infty) = r/(1+1/(\tau P)) \to r$ (for large P)

Extracting the System Time Constants

<u>Practical Solution:</u>

Create a simple application that

(1) provides auto-fit capabilities,
(2) is smart enough to determine whether to fit a rising exponential or a decaying exponential,
(3) allows intervention by the user to select limited fit ranges where necessary,
(4) reliably extracts the time constants, and
(5) can run on the user's computer without the need to purchase any software

Extracting the System Time Constants

Implementation:

Application written in IDL and deployed on the Sample Environment Team's computers with the IDL Virtual Machine (free-no license necessary)